National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
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GeoSTAR

A Breakthrough in Remote Sensing Technology

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Summary

- **GeoSTAR is a microwave sounder intended for GEO**
  - Ground-based proof-of-concept prototype has been developed
    - ***Excellent performance => Breakthrough development!***
  - Space-based version will be developed in time for GOES-R/S (2014-16)
- **Functionally equivalent to AMSU**
  - Tropospheric T-sounding @ 50 GHz with ≤ 50 km resolution
    - *Stand-alone all-weather temperature soundings*
    - Cloud clearing of IR sounder
  - Tropospheric q-sounding @ 183 GHz with ≤ 25 km resolution
    - *Stand-alone all-weather water vapor/liquid water soundings*
    - *Rain mapping*
    - *Tropospheric wind profiles* (Only feasible from GEO)
- **Using *Aperture Synthesis***
  - Also called Synthetic Thinned Aperture Radiometer (STAR)

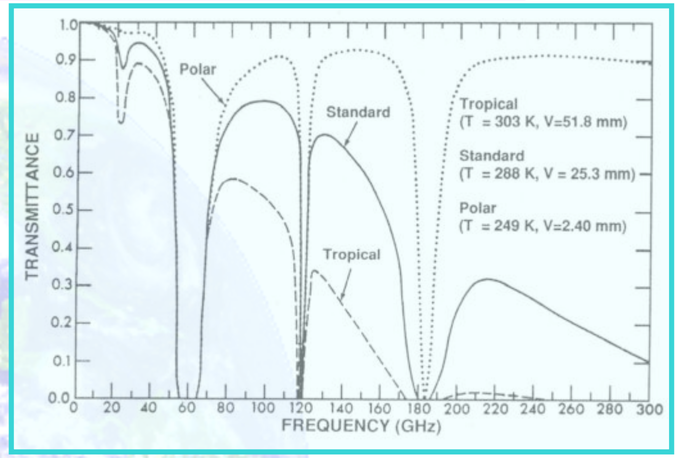
Why?

- **GEO sounders achieve high temporal resolution**
  - LEO: Global coverage, but poor temporal resolution; high spatial res. is easy
  - GEO: High temporal resolution and coverage, but only hemispheric non-polar coverage; high spatial res. is difficult
  - Requires equivalent measurement capabilities as now in LEO: IR & MW
- **MW sounders measure quantities IR sounders can't**
  - Meteorologically "interesting" scenes
    - Full cloud cover; Severe storms & hurricanes
  - Cloud liquid water distribution
  - Precipitation & convection
- **MW sounders complement IR sounders**
  - Complement primary IR sounder (HES) with matching MW sounder
    - Until now not feasible due to very large aperture required (~ 4-6 m dia. in GEO)
  - Microwave provides cloud/"cloud-clearing" information
    - Requires T-sounding through clouds - to surface under all atmospheric conditions
- **A MW sounder is one of the most desired GEO payloads**
  - High on the list of unmet capabilities

Why No MW/GEO Sounder Already?

- **Difficult to build large enough aperture**
  - AMSU-equivalence requires 6 meter parabolic dish: Difficult to stow and deploy
  - High surface fidelity required for adequate beam efficiency: Beam efficiency of 95%+ required for sounding
  - Mesh or film technology not available at sounding frequencies: Must use solid dish
    - Means large volume, mass, moment of inertia
- **Difficult to achieve adequate spatial coverage**
  - Dish antenna must be mechanically scanned: Difficult to scan very large dish
  - Scanning subreflector is problematic: Beam quality/efficiency degrades with scan angle
    - Therefore, scan range is limited
- **Difficult to overcome system limitations**
  - Mechanical scanning causes platform disturbances: Cannot coexist with super-high resolution imagers
  - Large platform resources required: Mass, power, volume, platform control
  - High risk at system level
  - Difficult to expand to meet future growing needs

Notional Measurement Requirements



- **Radiometric sensitivity**
  - Must be no worse than AMSU (≤ 1 K)
- **Spatial resolution**
  - At nadir: ≤ 50 km for T; ≤ 25 km for q
- **Spectral coverage**
  - Tropospheric T-sounding: Must use 50-56 GHz
    - Note: Higher frequencies (118 GHz, etc.) cannot penetrate to the surface everywhere (e.g., tropics)
    - Bottom 2 km (PBL) is the most important/difficult part and must be adequately covered
  - Tropospheric q-sounding: Must use 183 GHz (AMSU-B channels)
    - Note: Higher frequencies (325 or 450 GHz) cannot penetrate even moderate atmospheres
  - Convective rain: 183 GHz (AMSU-B channels) method proven
  - “Warm rain”: 89 + 150 GHz (Grody) - *maybe 50+150*
- **Temporal coverage from GEO**
  - T-sounding: Every 30 minutes @ 50 km resolution *or better*
  - Q-sounding: Every 10 minutes @ 25 km resolution *or better*

These are the performance goals for GeoSTAR #1 (to be improved by x2 next)

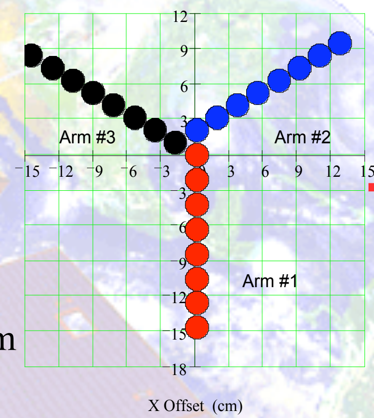
Applications

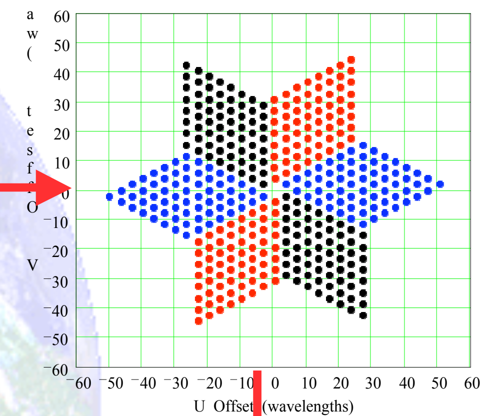
- **Weather forecasting**
  - All-weather soundings - standalone, but also complements IR soundings
  - Full hemispheric soundings @<50/25 km every 10-30 minutes (continuous) - *easily improved*
  - “Synoptic” rapid-update soundings => Forecast error detection => 4DVAR correction
  - “Differential sounding” to detect changes at time intervals 1 minute and up
- **Hurricane diagnostics**
  - Very large scattering signal from hurricanes/convection easily measurable
  - Measure location, intensity & vertical structure of convective bursts
  - Detect intensification/weakening in NRT, frequently sampled (~ 5-10 minutes)
- **Rain**
  - Full hemisphere @ ≤ 25 km every 5-10 minutes (continuous) - both easily improved
  - Complements GPM/TRMM: fill space-time gaps through data fusion
  - Measure snowfall, light rain, intense convective precipitation (per Weng and per Staelin)
- **Tropospheric wind profiling @ very high temporal resolution**
  - Surface to 300 mb; adjustable pressure levels; in & below clouds
- **Climate research - Hydrology cycle**
  - Stable & continuous MW observations => Long term trends in T & q and storm stats
  - “Science continuity”: GeoSTAR channels = AMSU channels

GeoSTAR System Concept

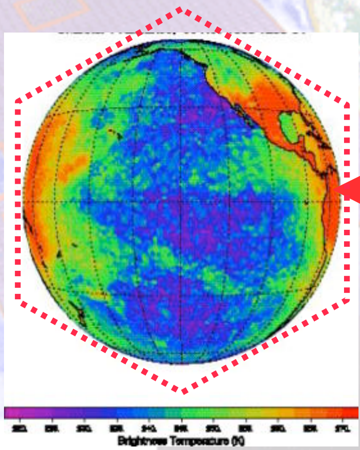
- **Concept**
  - Sparse array employed to synthesize large aperture
  - Cross-correlations -> Fourier transform of Tb field
  - Inverse Fourier transform on ground -> Tb field
- **Array**
  - Optimal Y-configuration: 3 sticks; N elements
  - Each element is one I/Q receiver, 3.5λ wide (2.1 cm @ 50 GHz; 6 mm @ 183 GHz!)
  - Example: N = 100 ⇒ Pixel = 0.09° ⇒ 50 km at nadir (nominal)
  - One "Y" per band, interleaved
- **Other subsystems**
  - A/D converter; Radiometric power measurements
  - Cross-correlator - massively parallel multipliers
  - On-board phase calibration
  - Controller: accumulator -> low D/L bandwidth

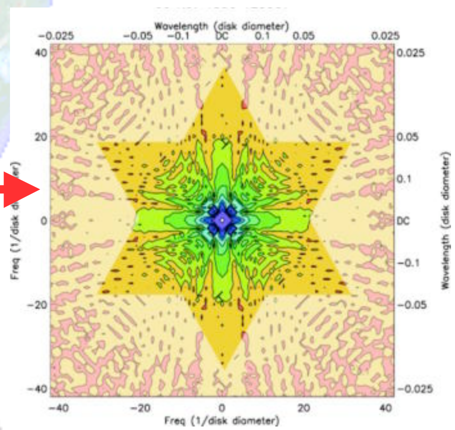
Receiver array & resulting uv samples





Example: AMSU-A ch. 1





What GeoSTAR Measures

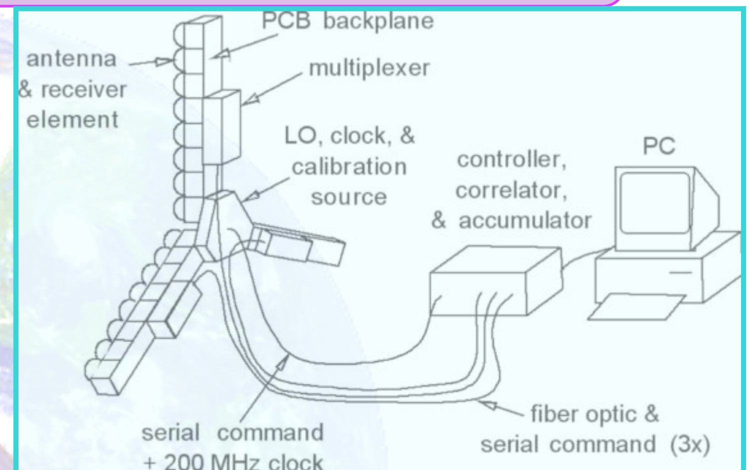
- **Visibility measurements**
  - Essentially the same as the spatial Fourier transform of the radiometric field
  - Measured at fixed uv-plane sampling points - One point for each pair of receivers
  - Both components (Re, Im) of complex visibilities measured
  - Visibility = Cross-correlation = Digital 1-bit multiplications @ 100 MHz
  - Visibilities are accumulated over calibration cycles —> Low data rate
- **Calibration measurements**
  - Multiple sources and combinations
  - Measured several times a second = calibration cycle
- **Interferometric imaging**
  - All visibilities are measured simultaneously - On-board massively parallel process
  - Accumulated on ground over several minutes, to achieve desired NEDT
  - 2-D Fourier transform of 2-D radiometric image is formed - *without scanning*
- **Spectral coverage**
  - Spectral channels are measured one at a time - LO tunes system to each channel

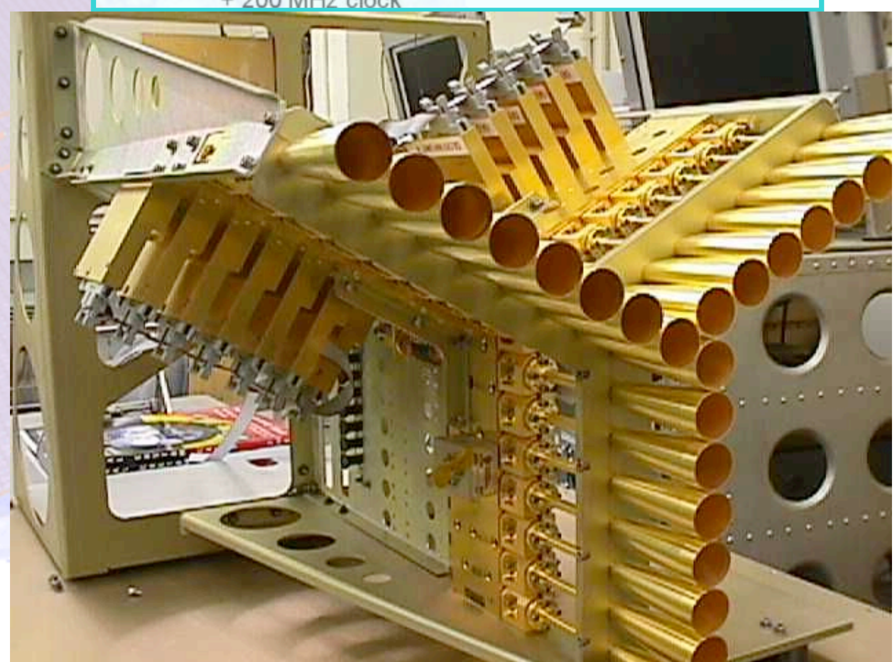
Calibration

- **GeoSTAR is an *interferometric* system**
  - Therefore, *phase calibration* is most important
  - System is designed to maintain phase stability for tens of seconds to minutes
  - Phase properties are monitored beyond stability period (e.g., every 20 seconds)
- **Multiple calibration methods**
  - Common noise signal distributed to multiple receivers —> complete correlation
  - Random noise source in each receiver —> complete de-correlation
  - Environmental noise sources monitored (e.g., sun’s transit, Earth’s limb)
  - Occasional ground-beacon noise signal transmitted from fixed location
  - Other methods, as used in radio astronomy
- **Absolute radiometric calibration**
  - One conventional Dicke switched receiver measures “zero baseline visibility”
    - Same as Earth disk mean brightness temperature (= Fourier offset, the “a_0 term” in a F-series)
  - Also: compare with equivalent AMSU observations during over/under-pass
  - The Earth mean brightness is highly stable, changing extremely slowly

GeoSTAR Prototype Development

- **Objectives**
  - Technology risk reduction
  - Develop system to maturity and test performance
  - Evaluate calibration approach
  - Assess measurement accuracy
- **Small, ground-based**
  - 24 receiving elements - 8 (9) per Y-arm
  - Operating at 50-55 GHz
  - 4 tropospheric AMSU-A channels: 50.3 - 52.8 - 53.71/53.84 - 54.4 GHz
  - Implemented with miniature MMIC receivers
  - Element spacing as for GEO application (3.5 λ)
  - FPGA-based correlator
  - All calibration subsystems implemented





Now undergoing testing at JPL!

Performance so far is excellent

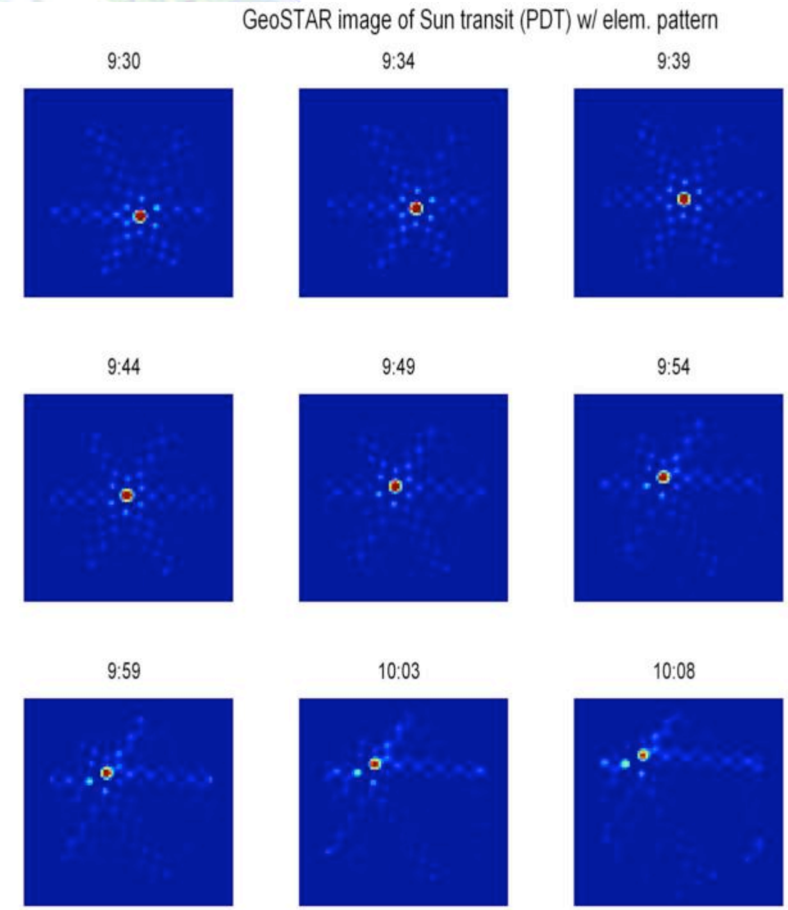
See Tanner's talk (next) re. test results

GeoSTAR First Light: Solar Transit at JPL

GeoSTAR taken outside to observe the sun

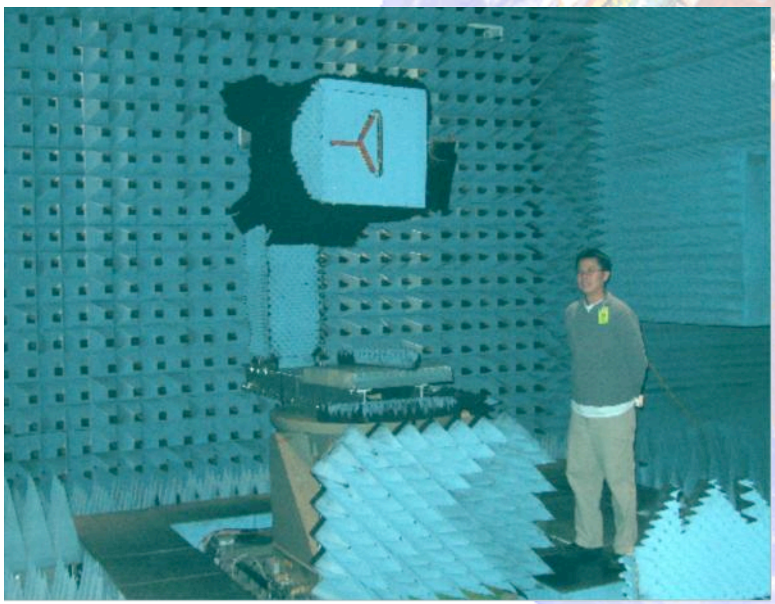
Pointed upwards at 45° elevation angle

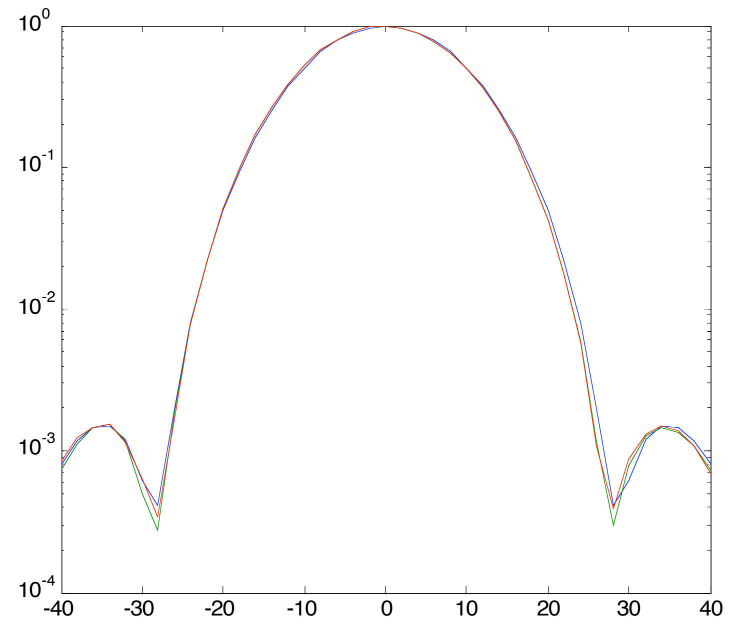
About 80 minutes of data during transit through ~20° FOR



Spatial response function is a 2D "sinc" function
"Ghosts" are sinc-function oscillations around zero - easily removed!

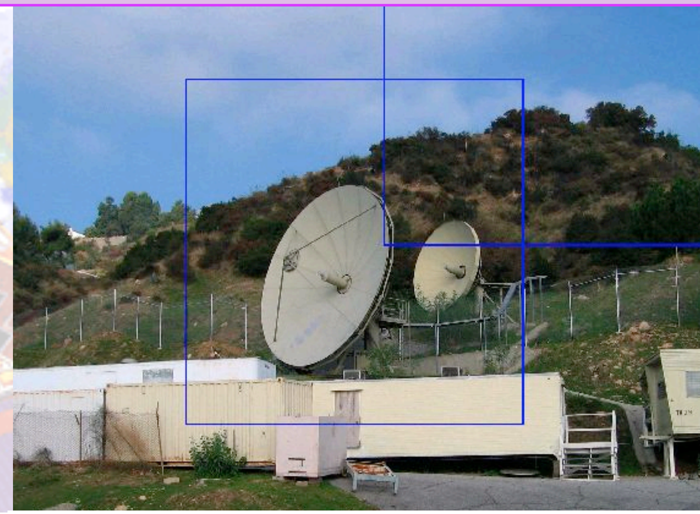
Antenna Tests at NASA GSFC





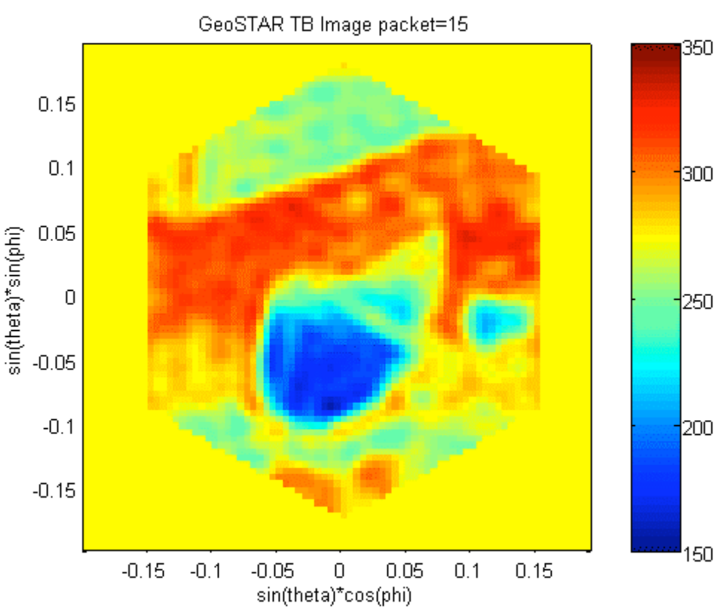
Excellent antenna patterns

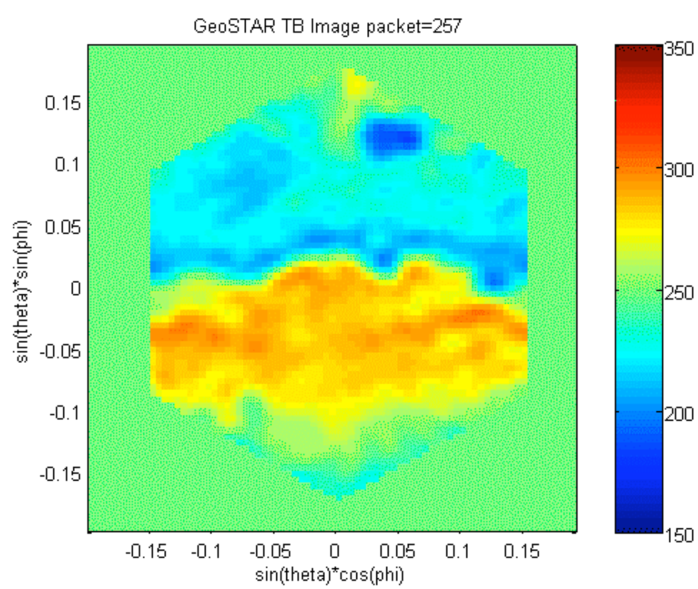
First Images of Real Scenes



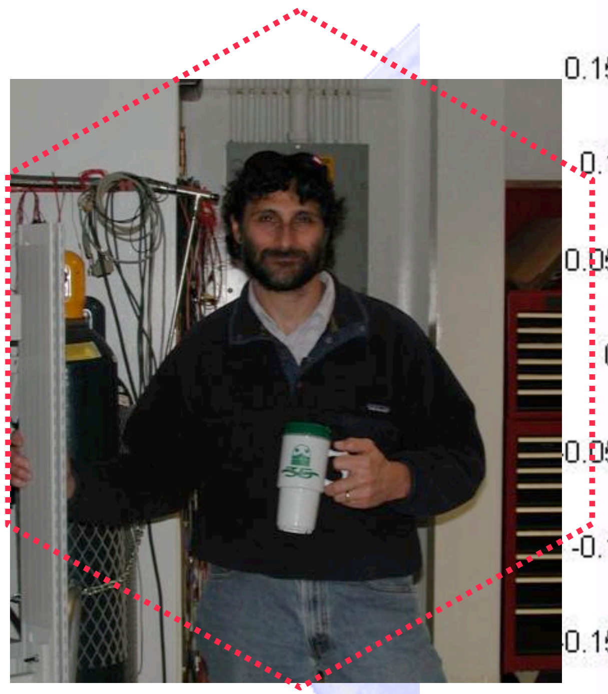
- **-Images reconstructed from 5-minute interferometric measurement sequences**
- **-Hexagonal central imaging area shown**
- **-Aliasing from outside central imaging area can be seen**
  - **These effects are well understood and can be compensated for, but they will not appear in GEO (background is uniformly 2.7 K)**

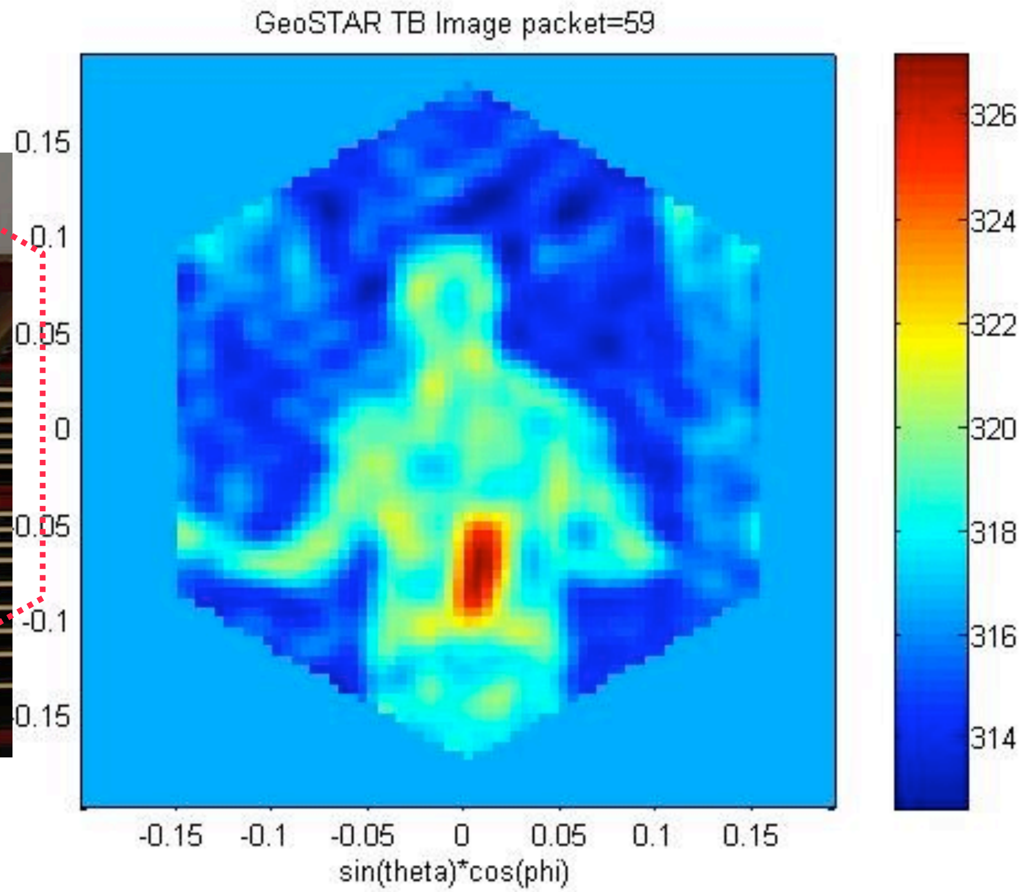
This is a first - a major achievement!





Indoor Target!



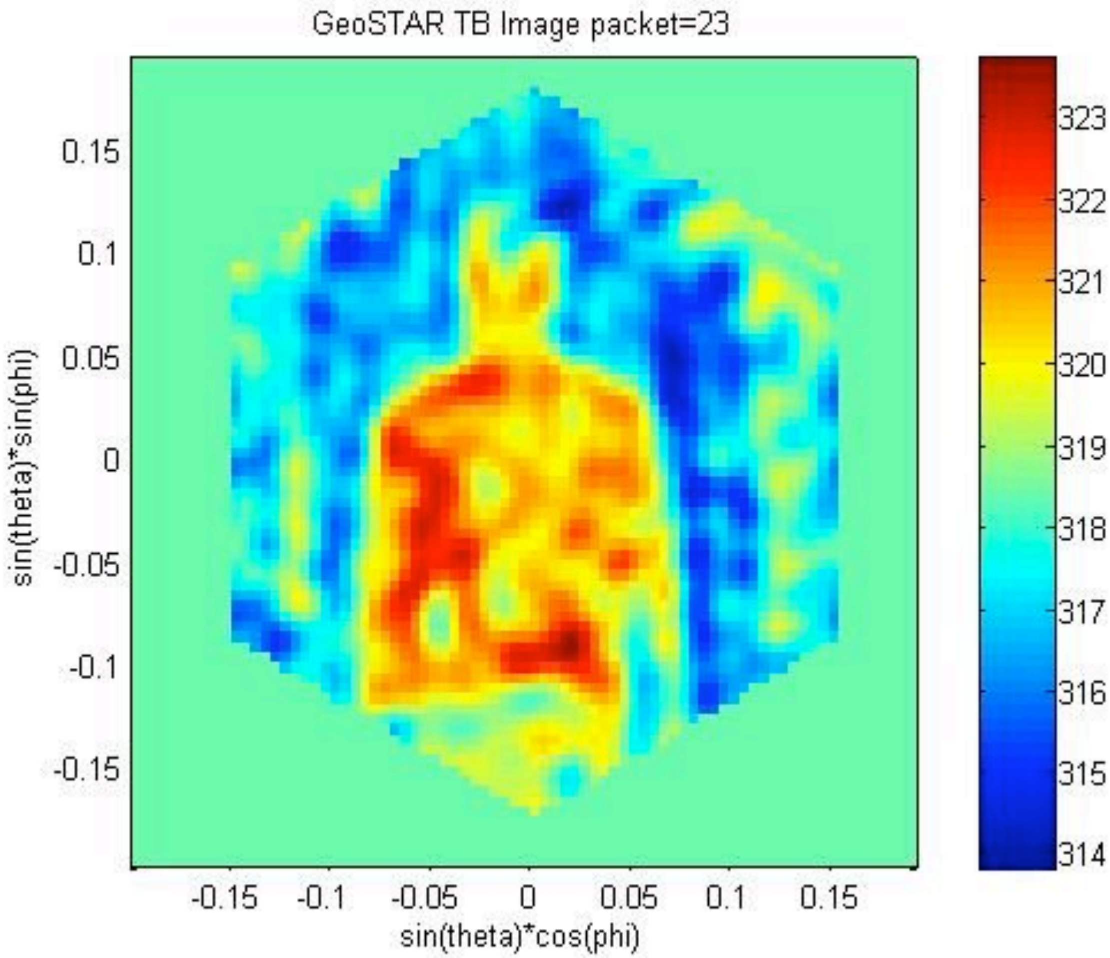


-We have developed a method to compensate for distortions when target is in near field

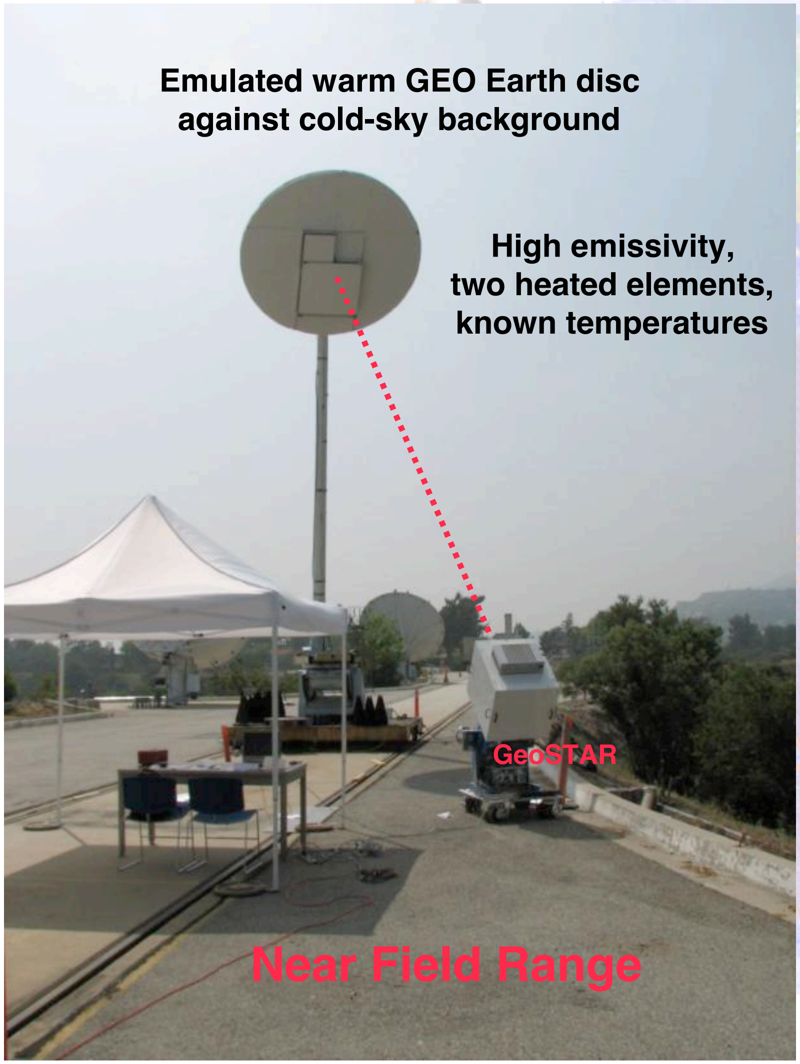
-This allows us to use near-field targets to measure the performance of the system

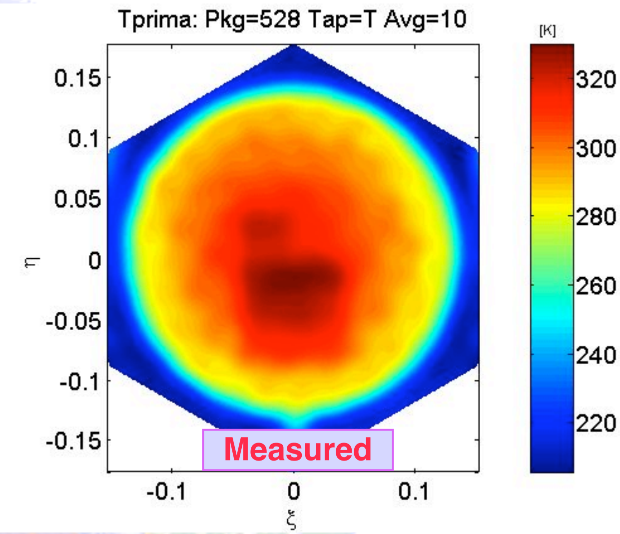
-An effort is now under way to measure mocked-up “Earth from GEO” calibration targets

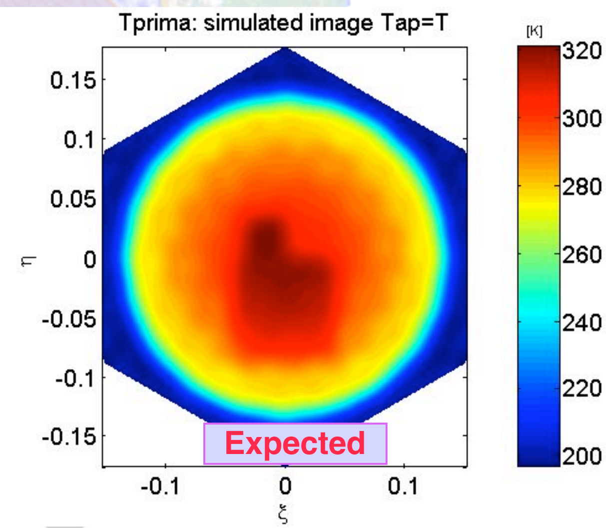
All Kinds of People In the Lab…



Quantitative Measurements Under Way



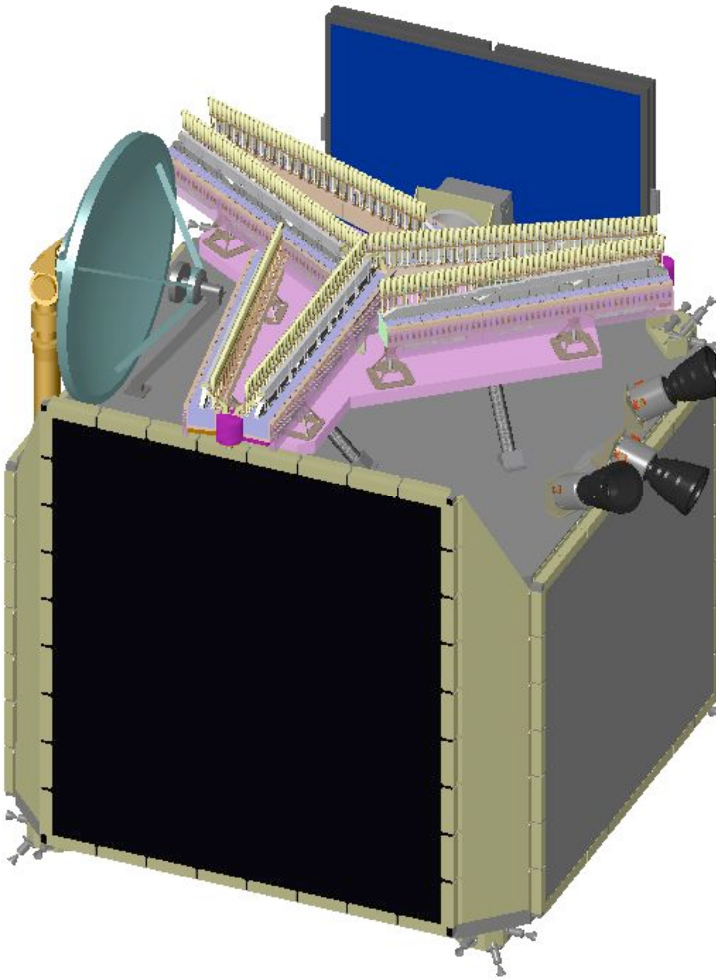




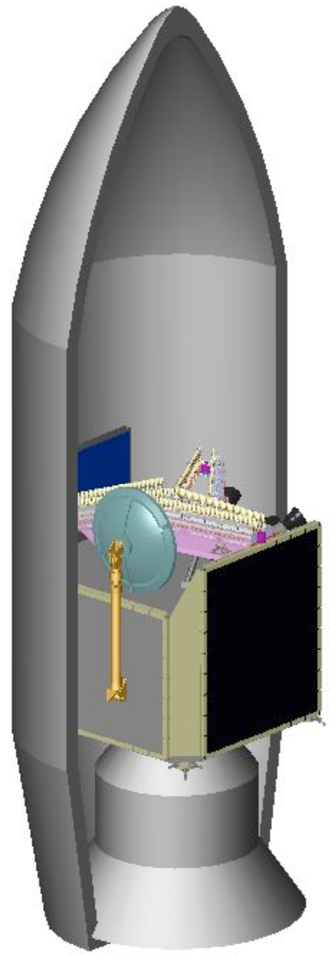
GeoSTAR vs. Real-Aperture Approach

Feature	GeoSTAR	Real aperture
Aperture size	Any size	Very limited
Scanning	No scanning	Mechanical scanning
Spatial coverage	Full disk	Problematic
Time to image full disk	10-20 minutes	~2 hours
Spectral coverage	One array per band	One antenna/N receivers
Accommodation	Easy	Difficult
Power consumption	Moderately high	Moderately low
Platform disturbance	None	High
Technology risk	High, but being retired	Moderate
Fault tolerance	High – inherent redundancy	Low – many single point failure items
Future expandability	Unlimited	Very limited

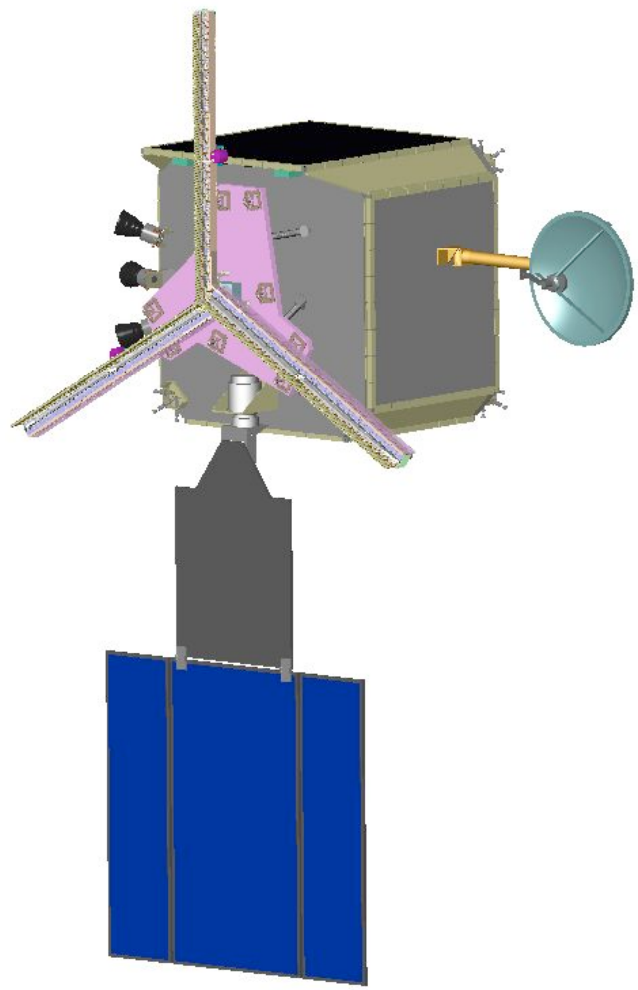
Accommodation Studies



Array arms folded for launch



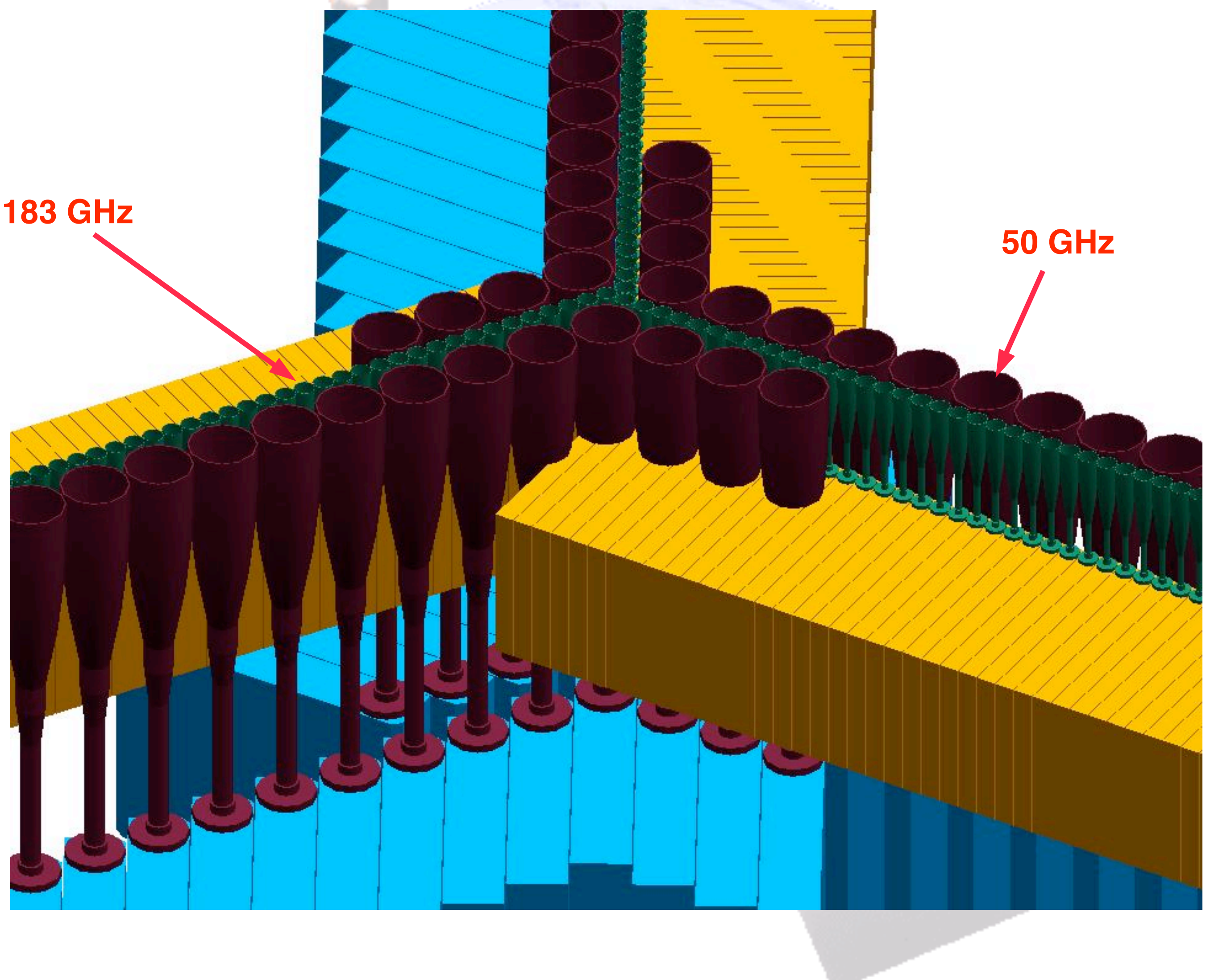
Stowed in Delta fairing



Deployed on-orbit

Ball Aerospace

Dual-Band Array Configuration



GEO Roadmap

- **Prototype: 2003-2006**
  - Fully functional system completed - now being tested & characterized
- **Further risk reduction: 2005-2008**
  - Develop 183-GHz compact/lightweight multiple-receiver modules
  - Develop efficient radiometer assembly & testing approach
    - Reduce cost per receiver
  - Migrate correlator design & low-power technology to rad-hard ASICs
- **Science and user assessment**
  - Forecast impact: OSSE under development
  - Algorithm development; applications
- **Space version (PFM): ~2008-2013**
  - Start formulation phase in 2008
  - Ready for launch in 2013 - Launch on GOES-R in 2014
- **Demonstration mission: ~2014-2015**
  - Joint NASA/NOAA mission
- **Transition to operational: ~2015**
  - Part of operational GOES

IIP Accomplishments

- **New remote sensing concept developed**
  - Complete, functional prototype constructed
  - Successful testing program
  - First successful demonstration of 2D STAR imaging
  - Qualitative results constitute proof of concept
  - Quantitative results prove adequate performance
- **Advanced TRL**
  - Aperture synthesis *system*
  - *Receiver* technology & packaging
  - *Antenna* elements
  - *Calibration* subsystems
  - Calibration *methodologies*
- **Getting ready for space mission!**
  - Conducted preliminary roadmap studies
  - Identified tall poles
  - Sponsored continuing technology development/risk reduction

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GEOSTAR
A BREAKTHROUGH IN REMOTE SENSING TECHNOLOGY

COMING SOON:

SEE THIS IN MICROWAVE!

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